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Characterization of the indoor particles and their sources in an Antarctic research station

Érica Coelho Pagel · Neyval Costa Reis Jr. · Cristina Engel de Alvarez ·
Jane Méri Santos · Melina Moreira Conti · Ricardo Salvador Boldrini ·
Américo Sansigolo Kerr

Abstract Many studies have been carried out on the environmental impact of the research stations on the Antarctic continent. However, the assessment of indoor air quality in these confined environments has been neglected. The main objectives of this study are to investigate the granulometric distribution of the indoor particles in the different compartments of the Brazilian Antarctic Station, to examine the number and mass concentration of the indoor particles, to conduct chemical and morphological analyses of the indoor $PM_{2.5}$, and to identify the possible sources of the PM. The results showed that Na, K, Cl, Fe, Zn, S and Si were the main elements detected. High levels of black carbon were recorded in the workshop, which may be associated with the use of diesel vehicles. To identify the human activities related to the indoor particle emission in the station, the size distribution of the particles in the living room was monitored for seven consecutive days, during normal station operation. It was possible to identify the influence of individual processes, such as incineration, cooking and the movement of people, upon the particle size number concentration. The indoor/outdoor (I/O) ratio for the total suspended particles (TSP), PM_{10}, $PM_{2.5}$ and PM_1 measured was significantly larger than those reported for urban buildings. In general, the I/O ratio distribution for all the compartments shows peak values between 2.5 and 10 μm, which is often related to human activity, such as cleaning, personnel circulation or clothing surfaces. The maximum I/O ratio at this range varied from 12 to 60. In addition, the compartments affected by combustion processes tend to present a significant number of submicron particles.

É. C. Pagel (✉) · N. Costa Reis Jr., · J. M. Santos
Department of Environmental Engineering, Universidade Federal do Espírito Santo, Av. Fernando Ferrari 514, 29.060-910 Vitória, ES, Brazil
e-mail: erica.pagel@gmail.com

É. C. Pagel · C. E. de Alvarez
Department of Architecture and Urbanism, Universidade Federal do Espírito Santo, Av. Fernando Ferrari 514, 29.060-910 Vitória, ES, Brazil

M. M. Conti · R. S. Boldrini
Instituto Federal do Espírito Santo, IFES, Av. Vitória 1729, 29.040-780 Vitória, ES, Brazil

A. S. Kerr
Institute of Physics, Universidade de São Paulo, P O Box 66318, 05314-970 São Paulo, SP, Brazil

Introduction

The Antarctic hosts the world's largest protected area. Its distance from potential sources of pollution raises scientific interest in quantifying the impact of anthropogenic activities away from the competitive influences found in large urban centres. A number of governments maintain permanent research stations in Antarctica. The extreme climate in this continent has led to the development of architectural designs of enclosed structures that provide both shelter and logistical support to the

researchers. However, the potential sources of air pollution originating from the functioning of the buildings and human activities can influence the composition of the local atmosphere in the long term (Mishra et al. 2004).

A number of studies have analysed the mass concentration and chemical composition of outdoor particles in the Antarctic (Pereira et al. 1992; Mishra et al. 2004; Pant et al. 2011; Teinilä et al. 2014). For instance, Mazzera et al. (2001) measured the black carbon concentration downstream from the North American station during summer and found concentrations twice as high as the measurements carried out in remote coastal areas in Antarctica. In spite of the importance of the indoor air quality in Antarctic buildings, indoor particles have not yet been a focus of attention.

The presence of particulate matter (PM) is associated with short-term health effects, such as irritation of the eyes, nose and throat; headaches; dizziness; and fatigue, contributing to various respiratory and cardiovascular problems (Annesi-Maesano et al. 2007) and symptoms of the sick building syndrome, which are particularly important for Antarctic buildings, since people may spend long periods indoors due to extreme weather conditions. Generally, fine particles inflict high levels of toxicity mainly due to the interaction of these particles with lung cells (Godish 2003), which indicates the importance of identifying the granulometric distribution of airborne particles, as well as the chemical composition of fine particles (Calvo et al. 2013).

Indoor particle concentration is a combination of outdoor particle infiltration and particle generation by internal sources (Santos et al. 2011). A number of human activities, such as cooking and cleaning, cigarette smoking, conducting and parking vehicles, using cosmetics, toiletries, candles and heating systems have been found to contribute to an increase in the concentrations of indoor particles (Buonanno et al. 2013; Géhin et al. 2008; Gupta et al. 2008; Uhde et al. 2015). At urban environments, naturally ventilated buildings present indoor/outdoor concentration ratios (I/O) for PM_{10} and $PM_{2.5}$ (particulate matter smaller than 10 and 2.5 μm, respectively) ranging from 0.5 to 0.98 and 0.54 to 1.08, respectively, in the absence of indoor sources (Morawska and Salthammer 2003). When indoor sources are present, I/O ratios for PM_{10} and $PM_{2.5}$ range from 1.14 to 3.91 and 1 to 2.4, respectively (Morawska et al. 2013). These ratios may be considerably larger for Antarctic stations because a general characteristic of

these edifices is the focus on energy efficiency, mainly regarding energy consumption and thermal comfort. Indoor air quality is not a matter of significant concern during building planning, especially for the older stations.

The present study is the first to investigate particulate matter within an Antarctic research station and the air quality level due to this pollutant. The main objectives of this study are (i) to investigate the granulometric distribution of indoor particles in a research station in the Antarctic, (ii) to examine the number and mass concentration of the indoor particles, (iii) to compare the concentrations found with the maximum exposure limits established by Brazilian and international laws, (iv) to conduct analysis of the chemical (elemental composition and black carbon—BC content) and morphological analysis of the indoor $PM_{2.5}$ and (v) to identify the possible sources of the PM.

Methods

The research station in the Antarctic

The Brazilian Antarctic Station (Estação Antártica Comandante Ferraz—EACF) is located in Admiralty Bay on King George Island at 62°05′ N 58°24 W and is populated by a group of approximately 65 people, consisting of both civilians and military personnel, who are permitted to stay in the station for periods ranging from 1 month to 1 year. The EACF was founded in 1984 and consisted of eight metal containers measuring 150 m^2 to accommodate up to 12 people. It underwent extensive renovation, and by 2012, the surface area was approximately 2500 m^2. In some compartments, which benefited from air heating systems, where windows exist, they normally were used to refresh the recycled indoor air (subjected to weather conditions). A fire destroyed a large part of the station in February 2012, and a new building will be constructed. Therefore, this study also intends to supply information to support the design of the new buildings to help reduce the sources of indoor air pollution and improve indoor air quality.

Figure 1 shows a schematic representation of the station, indicating the sampling points for the field experiment. The station is divided in two large environments consisting of (i) conditioned compartments and (ii) unconditioned compartments. The conditioned compartments are the living quarters of the station personnel,

Fig. 1 Schematic floor plan of the EACF indicating the sampling sites

encompassing the dormitories, gym, library, living room, kitchen and bathrooms. The unconditioned compartments are the service and utility areas, which include the station maintenance workshop, energy generation, incinerator, garage, storage and a transition area between the operating sectors (TA). While the conditioned areas have heating, the unconditioned areas have only basic protection from the outside weather (no temperature control). This arrangement is very common in Antarctic stations in general because the severity of the weather, especially during winter, restricts the movement between buildings. Thus, service areas are usually linked by a protected covered environment (TA), while living quarters and laboratories are conditioned environments. Another general characteristic of the Antarctic stations is the focus on the energy efficiency of the edifice, mainly regarding energy consumption and thermal comfort. Indoor air quality is not a matter of significant concern, especially for the older stations, such as the EACF.

Field experiments were conducted between 13 January and 3 February 2012, during the Antarctic summer when there is maximum station occupancy.

Particles were measured in three outdoor sites and at nine compartments, which were occupied for longer periods of time and contained potential sources of air pollution (Fig. 1). The sampling sites were grouped as follows: (i) conditioned compartments, consisting of two spaces used by all occupants (living room and library), spaces for private use (arsenal group dormitory—AGD, bedrooms 10 and 21); (ii) unconditioned compartments consisting of four service areas (workshop, incinerator area, garage and transition area between the operating sectors—TA) and (iii) outdoor sites, consisting of three monitoring points known as 'outstation I' (13.5 m from the front east side of the station), 'outstation II' (6.0 m from the rear west side of the station) and 'refuge II' (5 km away from the EACF).

In addition to particle measurements, a field logbook was made available to residents in each site to register their daily activities. Furthermore, residents completed a questionnaire based on EN ISO 16000-1/2006 for indoor air quality assessment (The European Standard 2006).

It is important to note that the experiments represent typical operating conditions for summer, when there is

maximum station occupancy (65 people) and the doors to the outside remain open more frequently. During winter, activities at the station are significantly reduced, occupancy is reduced to a minimum personnel (15 to 20 people) and doors to the outside remain mostly closed, due to extreme weather conditions and to the reduced vehicle usage.

Sampling techniques

Indoor and outdoor particles were analysed using an optical laser aerosol spectrometer (LAS—Dust Monitor 1.109, Grimm Technologies, Germany) that measures 31 particle sizes ranging from 0.25 to >32 μm at a 1-min frequency. This spectrometer works at a constant airflow rate controlled by a pump previously calibrated at 1.2 L/min ± 5 % and gives the mass and number concentration of the particles distributed by diameter. The LAS samples ambient air continuously and stores aerosol size distribution every minute. The 1-min size distributions are used to produce the 1-h and 24-h averaged size distributions presented in this work. The temperature, humidity and air velocity were also measured. For the indoor areas, the measurements were carried out during 24 h in all compartments, except in the living room where particles were monitored for seven consecutive days, as it was the most frequently used area within the station.

For the outdoor areas, the monitoring periods depended on the weather conditions; particles were monitored in outstation I during 7 h and 2 h in refuge II. The measurements were not conducted simultaneously in all outside and inside sampling sites.

In addition, $PM_{2.5}$ sampling for the chemical and morphological analyses was carried out using two MiniVol portable particulate samplers (Minivol, Airmetrics, USA) using Teflon filters (Whatman International Limited, USA). These samplers were placed 1.5 m high and operated for a period of 24 h, except in the living room and outstation I where samplings were performed simultaneously for seven consecutive days. Wherever possible, for indoor areas, the samplers were located at the centre of the compartments (The European Standard 2006). A total of 43 samples and five field-control samples, as well as five laboratory-control samples were collected.

Chemical and morphological analyses

The chemical composition of the $PM_{2.5}$ was determined by an energy dispersive X-ray spectrometer (EDX 700 HS, Shimadzu), which detects and quantifies elements with atomic numbers from 11 to 82. The concentration was measured using a smoke stain reflectometer (Diffusion Systems Ltd., Model 43), which relates the amount of light reflected by the filters with its BC contents (the calibration curve was defined empirically as recommended by Loreiro et al. (1994) and was also used by Albuquerque et al. (2012)).

The morphological analyses were performed using a low-vacuum scanning electron microscope with individual-particle X-ray analysis—SEM/EDX (ZEISS, EVOMA10) at a saturation current of 2.5 A. The particles were identified using AZtecEnergy software (Oxford Instruments). The filters were cut to approximately 1 cm^2, placed in a sample holder and coated in a thin gold layer to a thickness of approximately 20 nm using an Argon plasma sputter (Quorum Q150R ES) to avoid impairment due to electrostatic charges during image scanning.

Results and discussion

The results presented in this paper are divided in three main sections. The "Chemical and morphological characterization of fine particles" section presents the chemical and morphological characterization of the particles found, discussing a probable origin of each type of particle. The "Size distribution, number and mass concentration of particles" section presents the size distribution, number and mass concentration of the particles (TSP, PM_{10}, $PM_{2.5}$ and PM_1) at each compartment, and relates the values measured to the occupation, activities and/or building materials of the station. Finally, the "Concentration time series of a common use compartment" section presents the concentration time series of a commonly used compartment (living room), discussing the daily evolution of the particle concentration and size distribution based on the compartment use.

Chemical and morphological characterization of fine particles

Figure 2 shows images SEM/EDX of a few examples of the more frequent types of particles found in the
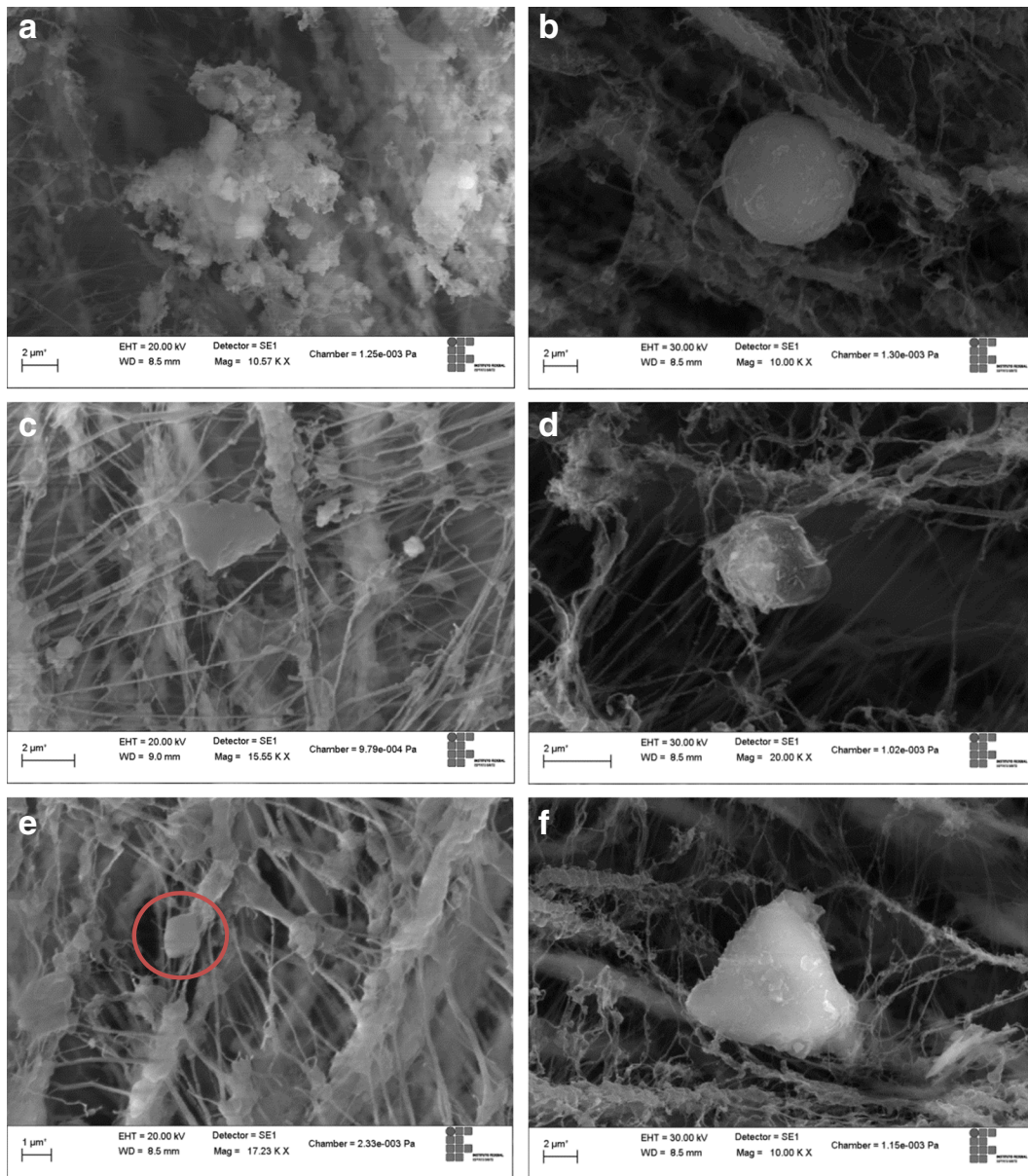
Fig. 2 SEM/EDX images of indoor PM$_{2.5}$ that show **a** agglomerates, **b** spherical particles and other morphologies of particles containing **c** iron, **d** zinc, **e** sea salt and **f** silicates

samples. Figures 3 and 4 present the concentration of each element and the BC found in the PM$_{2.5}$ samples collected. The results show that elements such as Na, Al, Si, S, Cl, K, Ca and Fe are the main elements found in PM$_{2.5}$ inside and outside the station. Na and Cl are most likely from the sea, while the other elements are commonly associated with the resuspension of particles from soil of geological origin, building materials or combustion processes.

The dominant Na and Cl concentrations shown in Fig. 3 were found in most of the samples and indicated a strong influence of the station's proximity to the sea. The SEM/EDX of the filters show several salt particles in the collected samples (Fig. 2e).

There is also a significant presence of Fe in the particles inside and outside the station (Fig. 2c). The living room and the workshop presented the highest mean concentrations of Fe. In the Antarctic region, Fe

a

b

c
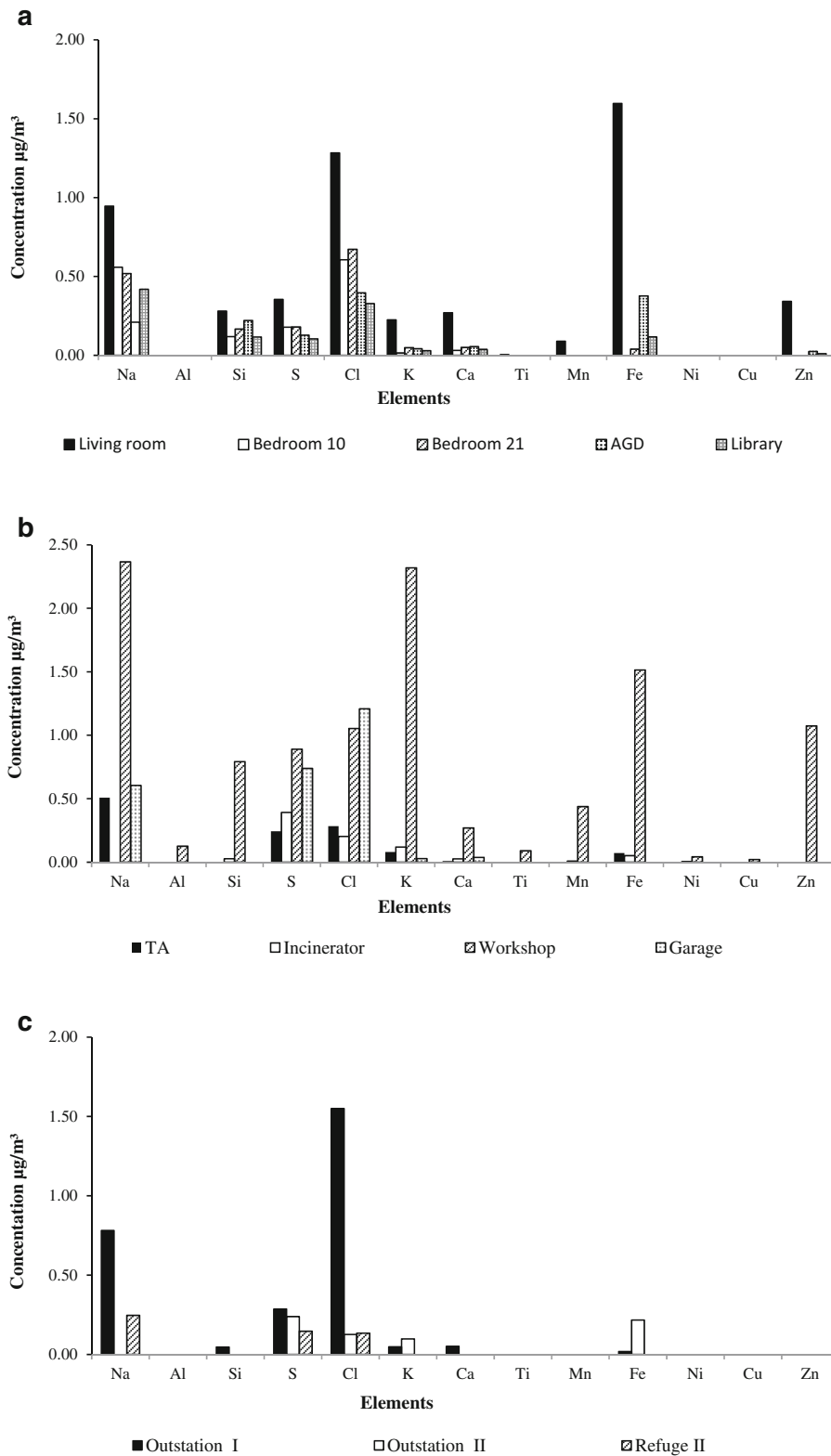
Fig. 3 Mean concentrations of major chemical elements found in the **a** conditioned and **b** unconditioned compartments and **c** external sites
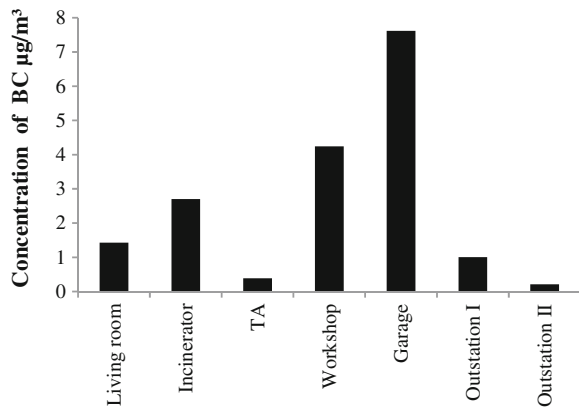
Fig. 4 Twenty-four-hour mean mass concentrations of BC in different monitoring sites

may be originated by soil erosion and, especially, by intense corrosive process of the metal containers in the station (Alvarez et al. 2007). These values of the Fe concentrations are half of those found by Chithra and Shiva Nagendra (2013), for instance, in indoor areas located in large urban region (approximately 4.68 million residents). In outstation II, the concentrations of Fe (0.22 $\mu g/m^3$) were higher than in the other two external points, and this could be related to the maintenance work carried out at the back of the station during the monitoring campaign. No Fe concentration was detected 5 km away from the EACF (refuge II), indicating the impact of the station upon the local Fe concentration.

As suggested by Weinstein et al. (2010), S is likely related to emissions from burning fuel oil in vehicles and the exhaust of diesel machines; therefore, it can be considered as a good marker for particles emitted outdoors and infiltrated in buildings in urban areas. A similar trend was observed at EACF, where S was found in all compartments. In EACF, all heating and electricity depends on diesel power generators and boilers. In fact, the highest mean concentration of S (0.89 $\mu g/m^3$) was found in the workshop, probably related to the proximity with the diesel power generators and the diesel vehicle traffic in this area. Outside the EACF, the S concentrations in the close vicinity of the station (outstation I and II) were nearly two times higher than the value found in refuge II.

A significant concentration of fine Zn particles (Fig. 2d) was found in several building compartments. Zn is mainly found in the particles smaller than 0.5 μm (Seinfeld and Pandis 2006) and can originate from cigarette smoke (Viana et al. 2011) and waste incineration (Li 1994). In addition, dust from paint is another likely

source of Zn (Huang et al. 2010), which may represent a significant contribution because the external and internal metal walls of the station had been recently painted with a solvent-based paint. The highest concentrations of this element were found in the workshop and in the living room (1.07 and 0.34 $\mu g/m^3$, respectively).

BC is an important marker of vehicular and combustion sources. A significant presence of BC was found in only 19 of the 43 samples analysed (Fig. 4). The highest concentrations were detected in the unconditioned compartments, which are mainly related to service areas (garage, workshop, the incinerator area and the transition area between the operating sectors—TA). The highest concentrations of BC were found in the garage and in the workshop (7.61 and 4.24 $\mu g/m^3$, respectively), showing the influence of the vehicles and the proximity of the diesel power generators on the particle concentration. Significant concentrations were also found in the incinerator area and in the TA, which is characterized by the intense circulation of personnel and light vehicles. No significant presence of BC was found in the conditioned compartments, except the living room. This fact may be related to infiltration from the TA.

The BC concentrations in the close vicinity of the station was significantly lower than the values found in the service areas of the station (unconditioned compartments), which indicates the need for more appropriate ventilation in these areas. The BC concentration at the point located 5 km away from the EACF (refuge II) was not detectable.

Size distribution, number and mass concentration of particles

Figure 5 shows the 24-h mean number concentration, temperature and humidity inside and outside the EACF. The number concentrations shown in Fig. 5 were not taken simultaneously because the measurements were performed on different days in each compartment. Nonetheless, all the compartments were monitored during the normal operation conditions of the station. The 24-h mean temperature recorded in the conditioned and unconditioned areas was 25.9 and 8.6 °C, respectively. As expected, the 24-h mean relative humidity was lower in the conditioned areas (26.9 %) than in the unconditioned ones (53.8 %). The average temperature recorded in refuge II was 4.89 °C.

Fig. 5 Twenty-four-hour mean number concentration of particles in various areas inside and outside the EACF and indoor environmental conditions
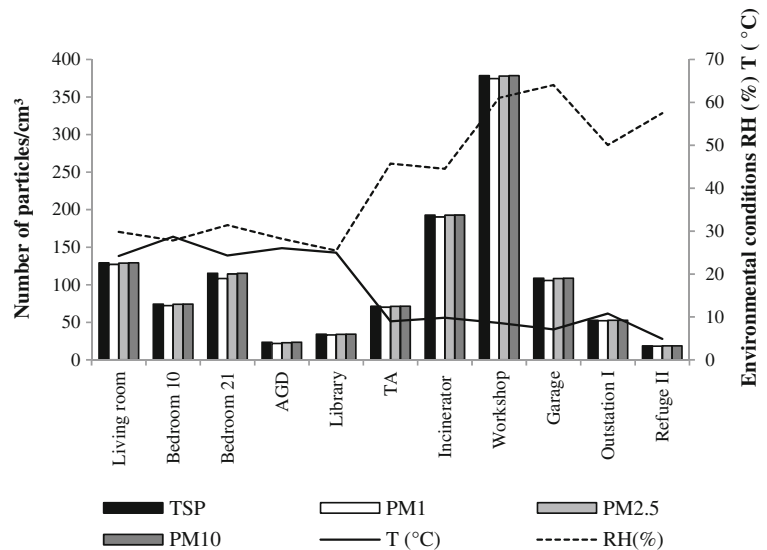
In general, the conditioned compartments present a smaller number of particles than the unconditioned compartments. In addition, the number of particles indoors is significantly greater than the number of particles outdoors, indicating that the generation of particles indoors from various processes is likely more important than the infiltration of particles from the outside. Likewise, the number of particles in the close vicinity of the station (outstation I = 52.7 particles/cm³) is considerably larger than the number of particles found 5 km away from the EACF (refuge II = 18.6 particles/cm³), demonstrating the local impact of the station.

Among the unconditioned compartments, the workshop and incinerator present the largest number of particles. Workshop-related activities, such as welding, painting, sawing and the transit of vehicles and people, contribute to an increase in the number of particles in this area. The large number of particles in the area of the incinerator may indicate that, although the incinerator is equipped with a gas treatment device for the exhaustion of gases, fugitive emissions are still significant.

The number of particles in the TA is smaller than in the other unconditioned areas. In spite of the emissions in the other service areas and the circulation of personnel and light vehicles, the gates were kept open during the daytime in summer, which contributes to the infiltration of clear air from outdoors and also tends to reduce particle number concentration in the garage.

Among the conditioned compartments, the living room presented the largest concentration number, which is likely related to the more intense activities of the station personnel in this area, including recreation, dining and socialization. In addition, the living room is integrated with the kitchen, which is one of the most important sources of particles, because cooking is often one of the main sources of indoor particles, especially submicron particles (He et al. 2004; Wan et al. 2011). On the other hand, the library presented the smallest concentration number among the conditioned compartments, which can be attributed to the type of usage of the compartment.

Although the function of the personnel accommodations, bedroom 10, bedroom 21 and AGD, is similar, the three compartments exhibit a very different concentration number of particles; the profile of the occupants significantly changes the particle emission in the compartment. While bedroom 10 and bedroom 21 house only two people, AGD houses 12 people. The accommodation areas are used during non-working hours and are therefore unoccupied throughout most of the day. The high concentration of PM in bedroom 21 is likely related to the specific activities of hygiene and personal care, including the intensive use of spray products (as recorded in the field logbook). Isaxon et al. (2015) indicate the use of spray products as one of the most intense sources of submicron particles.

The differences between compartments can be better understood by examining Fig. 6, which presents the size distribution of the I/O ratio, i.e. the number of particles found at each size range for a given compartment divided by the average number of particles found at each size range outdoors (in the close vicinity of the station—
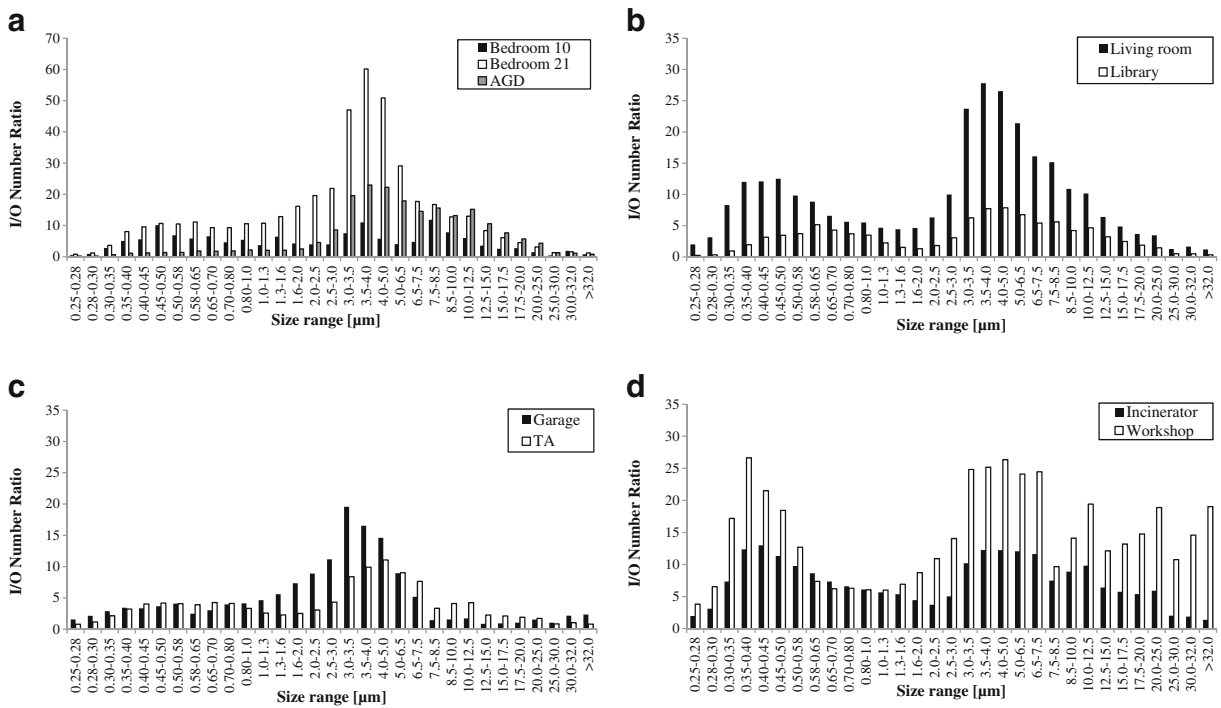
Fig. 6 Size distribution of the I/O number ratio of particles. **a** Bedroom 10, bedroom 21 and AGD. **b** Living room and library. **c** Garage and TA. **d** Incinerator and workshop

outstation I). The I/O ratio is greater than 1 for almost all of the size groupings (Figure 6a). For all three compartments, there is a peak of the I/O ratio for particles between 2.5 and 10 μm, indicating an intense emission of particles at these size ranges. Earlier studies have reported that resuspended materials observed indoors during human activity are characterized by a predominant emission of particles greater than 1 μm, such as indoor work, cleaning (Abt et al. 2000) and clothing surfaces (McDonagh and Byrne 2014). These findings are fairly consistent with the distribution presented in Fig. 6a.

The I/O ratio distribution for the other conditioned compartments (living room and library), shown in Fig. 6b, is very different from the pattern for bedroom 10, bedroom 21 and AGD. Although particle resuspension is important in the living room, which is indicated by an I/O ratio peak between 2.5 and 10 μm, there is also a considerable particle emission in the submicron range. The living room is adjacent to the kitchen, which is one of the most important sources of particles on the submicron range (He et al. 2004; Wan et al. 2011). Therefore, the I/O ratio distribution for the living room is a bimodal distribution, presenting two distinct peaks:

the first in the submicron range, between 0.30 and 0.70 μm, which is probably related to cooking, and the second peak between 2.5 and 10 μm, which is probably related to human activity, such as indoor work, people movement and cleaning.

For the unconditioned compartments, the I/O ratio distribution is also dependent on the type of activity. The TA and garage present distributions characterized by a single peak between 2.5 and 10 μm (Fig 6c), likely related to particle resuspension due to people and vehicle activities. There is a slight increase of submicron particles centred approximately at 0.5 μm, which is probably related to the internal combustion engines of the vehicles.

Analogous to the behaviour found in the living room, the workshop and incinerator areas also present a bimodal distribution of particle size, where the I/O ratio peaks for the larger particles (peak between 2.5 and 10 μm) are as important as the I/O ratio peaks for the submicron particles. For both compartments, the submicron particle generation is very important. At the incinerator area, the emission due to solid waste mechanical manipulation (waste handling and loading operation) tends to produce larger particles, while the fugitive emission from

combustion process inside the incinerator tends to generate submicron particles. At the workshop, the manufacturing and maintenance processes generate a wide distribution of particles, ranging from submicron to very large particles (>10 μm). The former emissions are related to welding and the combustion of oxyacetylene torches, and the latter is likely related to mechanical processes, such as metal cutting and carpentry. It is interesting to note that the variety of mechanical operations performed at the workshop present a very wide distribution of particle sizes, especially above 2.5 μm.

Figure 7 shows the mass concentration distribution for particle sizes for each compartment. For the conditioned compartments, most of the particle mass is in the range between 1 and 25 μm. Although bedroom 10, bedroom 21 and AGD (Fig. 7a) present a similar trend, bedroom 21 presents a distribution more biased to the smaller particles, while AGD presents a distribution more biased to the larger particles; these trends are probably related to the reported use of spray products and the circulation of the larger number of occupants, respectively.

The unconditioned compartments present distributions with the significant presence of even larger particles in relation to the conditioned compartments. These compartments are characterized as services areas, where the emission pattern is less related to human household activity and more linked to the nature of the services performed. For instance, the garage and TA show a significant presence of particles larger than 10 μm due to vehicle traffic.

Figure 8 presents the mass concentration of TSP, PM_{10}, $PM_{2.5}$ and PM_1 for each compartment. The I/O ratio for TSP, PM_{10}, $PM_{2.5}$ and PM_1 ranges from 2.4 to 14.2, 3.2 to 17.9, 1.8 to 10.4 and 0.98 to 8.9, respectively. These values are significantly larger than those reported for urban buildings (Morawska and Salthammer 2003; Morawska et al. 2013).

The mean mass concentrations found were compared with the maximum indoor exposure limits for PM as established by national (Brazilian) and international legislation (Fig. 8). The Brazilian air quality standard establishes a limit of 80 μg/m³ for the 24-h mean concentration of TSP (ANVISA 2003), which exceeded in the living room, bedroom 21, AGD and workshop. Regarding WHO guidelines (WHO 2010), the limit for PM_{10} exceeded in the living room, bedroom 21 and workshop. However, in comparison with the limits established by the standards
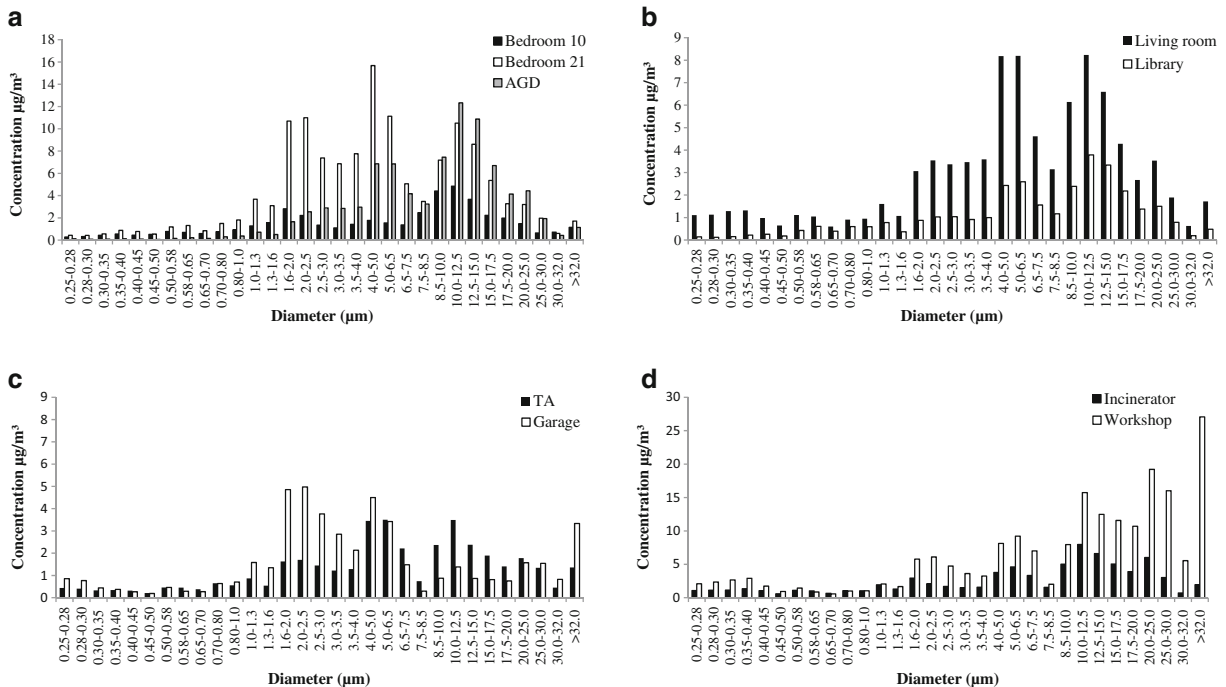
Fig. 7 Mass concentration distribution for particle sizes. **a** Bedroom 10, bedroom 21 and AGD. **b** Living room and library. **c** Garage and TA. **d** Incinerator and workshop
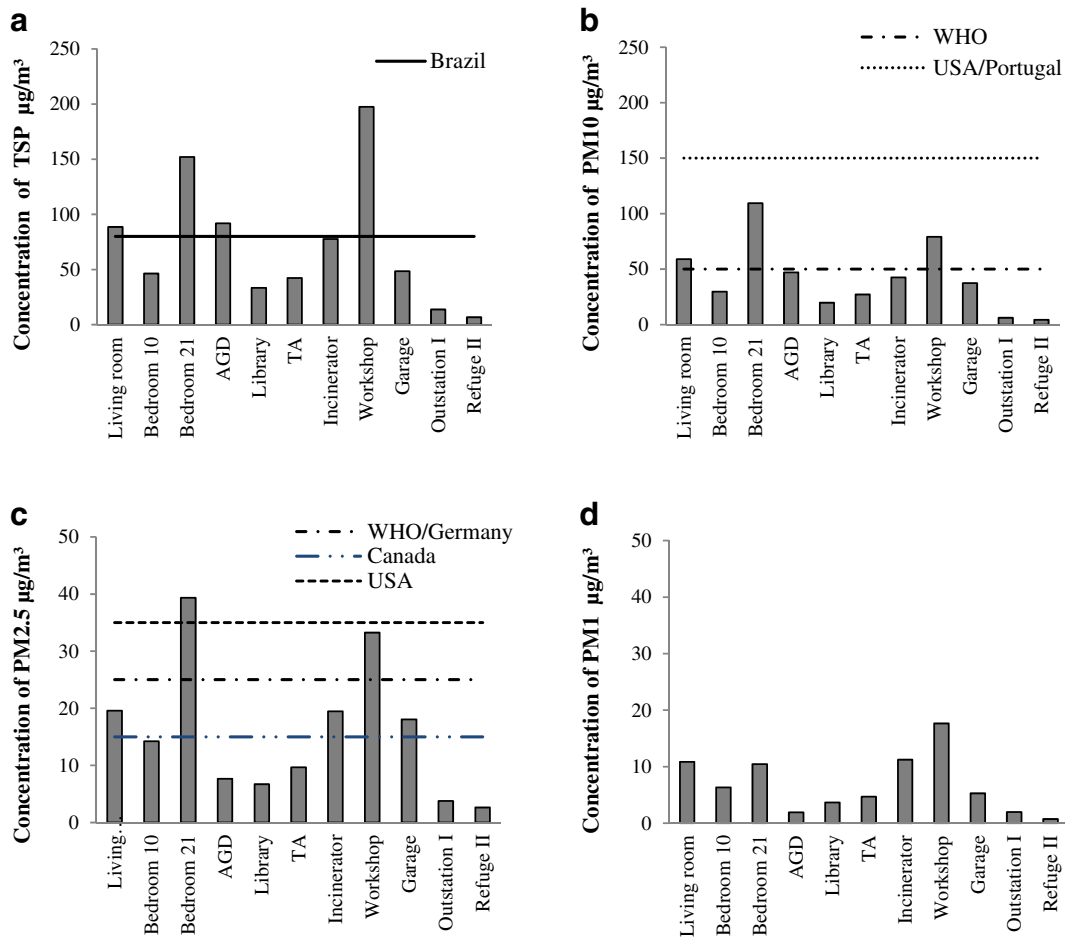
Fig. 8 Comparison between the 24-h mean concentrations of **a** TSP, **b** PM$_{10}$, **c** PM$_{2.5}$ and **d** PM$_1$ and indoor air quality standards in various countries and WHO guidelines

in the USA (NAAQS/EPA 2012) and Portugal (SCE 2009) (both limits are 150 μg/m^3 for 24-h mean concentration), no compartment exceeded the recommended standard.

For PM$_{2.5}$, certain countries use the 24-h mean concentrations of PM$_{2.5}$ to address indoor air quality. Canada, for instance, adopts limits of 15 and 35 μg/m^3 as indoor air quality standards for non-smoking and smoking environments, respectively (Health Canada 2014). The USA adopts 35 μg/m^3 as the limit values, while the German standard and WHO guidelines indicate 24-h mean concentration of PM$_{2.5}$ as 25 μg/m^3. During the monitoring period, only one compartment exceeded the 35-μg/m^3 limit (bedroom 21), two compartments exceeded the 25 μg/m^3 (Bedroom 21 and workshop) and five compartments exceeded the 15 μg/m^3 (living room, bedroom 21, incinerator, workshop and garage).

Concentration time series of a commonly used compartment

To identify the human activities related to the indoor particle emission in the station, the size distribution of the particles in the living room was monitored for seven consecutive days, during normal station operation. Table 1 presents a summary of the number and mass concentration of the PM and the environmental conditions in the living room recorded during the experiment. The monitoring conducted on 21 January 2012 was excluded from the evaluation due to the use of a fog machine during a social gathering in the room.

The mean temperature in the living room was 24.66 °C and the relative humidity was 27.40 %, due to an air heating system. Low relative humidity (between 20 and 30 %) can cause allergic and respiratory

Table 1 Measurement data obtained by LAS in the living room

Sampling time	Number of particles/cm³ (st.d.)				Mass concentration µg/m³ (st.d.)				Environmental conditions (st.d.)		
	PM_1	$PM_{2.5}$	PM_{10}	TSP	PM_1	$PM_{2.5}$	PM_{10}	TSP	T (°C)	RH (%)	Air velocity (m/s)
01/15/2012 Sunday (00:00–23:59)	70.58 (90.18)	72.16 (90.32)	72.46 (90.36)	72.47 (90.36)	4.54 (4.53)	11.46 (7.07)	40.43 (21.68)	77.22 (49.18)	24.54 (1.39)	25.59 (3.46)	0.0023 (0.0023)
01/16/2012 Monday (00:00–23:59)	92.34 (126.97)	93.67 (127.15)	94.00 (127.21)	94.01 (127.21)	4.41 (4.42)	10.49 (6.73)	39.05 (20.60)	62.87 (35.90)	24.51 (1.55)	25.67 (4.53)	0.0024 (0.0028)
01/17/2012 Tuesday (00:00–23:59)	194.44 (306.35)	196.58 (307.23)	197.05 (307.36)	197.06 (307.36)	10.86 (17.66)	19.56 (23.05)	58.92 (97.75)	88.64 (134.54)	24.23 (0.99)	29.84 (4.18)	0.0028 (0.0028)
01/18/2012 Wednesday (00:00–23:59)	226.33 (336.86)	228.54 (336.77)	228.81 (336.79)	228.82 (336.79)	11.57 (12.35)	20.12 (12.53)	42.84 (19.47)	65.80 (32.60)	25.19 (2.17)	28.90 (4.63)	0.0024 (0.0023)
01/19/2012 Thursday (00:00–23:59)	93.61 (182.79)	95.24 (183.17)	95.53 (183.18)	95.54 (183.18)	5.71 (8.64)	12.49 (10.55)	37.78 (21.56)	62.13 (37.41)	24.77 (1.43)	27.95 (2.91)	0.0032 (0.0032)
01/20/2012 Friday (00:00–23:59)	85.49 (109.95)	86.80 (110.57)	87.11 (110.67)	87.12 (110.67)	4.42 (4.77)	10.27 (9.64)	39.18 (28.33)	65.21 (45.86)	24.73 (1.54)	26.46 (4.57)	0.0024 (0.0031)
01/21/2012 Saturday (00:00–13:59)	2617.43 (4931.27)	2842.57 (5400.95)	2847.92 (5411.26)	2847.94 (5411.28)	405.68 (804.14)	1279.69 (2816.6)	1466.41 (3180.7)	1521.63 (3211.8)	23.14 (1.48)	31.53 (3.93)	0.0032 (0.0042)
Mean[a]	127.13	128.83	129.16	129.17	6.92	14.06	43.03	70.31	24.66	27.40	0.00
Min[a]	70.57	72.15	72.46	72.47	4.41	10.27	37.78	62.12	24.23	25.59	0.00
Max[a]	226.32	228.54	228.81	228.81	11.57	20.12	58.92	88.64	25.19	29.84	0.00
SD[a]	65.78	66.14	66.16	66.16	3.37	4.54	7.97	10.51	0.32	1.76	0.00

[a] Statistical parameters calculated considering 6 days from 00:00 on Sunday to 23:59 on Friday (does not include data from Saturday)

complications due to the dryness of the mucous membranes, nosebleeds, dry skin and eye irritation, especially when associated with poor air quality (Wolkoff and Kjærgaard 2007).

Several studies relate PM suspension to occupants' movements and to cleaning activities (Wallace et al. 2006; Qian et al. 2014). The highest maximum number concentration of TSP was recorded on Wednesday, followed by Tuesday and Thursday. On Wednesday and Thursday, the high reading was attributed to the use of the waste incinerator for several hours. The incinerator is located at a considerable distance from the living room, but its effect was still noticeable.

The largest 24-h mean mass concentrations of $PM_{2.5}$ and PM_1 were found on Wednesday (20.12 and 11.57 µg/m³, respectively), followed by Tuesday and Thursday. On the other hand, the highest PM_{10} 24-h mean mass concentration (58.92 µg/m³) was found on Tuesday, the cleaning day, followed by Wednesday when the incinerator was run for 12 hours. Similarly, the largest 24-h mean number concentrations of $PM_{2.5}$ and PM_1 were found on Wednesday (228.54 and 226.33 particles/cm³, respectively), followed by Tuesday and Thursday. However, the highest PM_{10} 24-h mean number concentration (228.81 particles/cm³) was also found on Wednesday followed by Tuesday.

Therefore, it is evident that the fine particles generated by the incineration contributed to the high number concentration of PM in the living room on Wednesday. The fine particles prevail in high numbers, but due to their small sizes, they represent only a small percentage of the total mass of PM (Seinfeld and Pandis 2006). In addition, a smaller particle can travel a longer distance and stay suspended for a longer period than a large particle, thereby reaching the living room and infiltrating other compartments. The cleaning activities (sweeping the floor and cleaning the furniture) contribute to the suspension of the fine and coarser particles that have settled on the floor and furniture, thus contributing to an increase in the particle number and mass concentration.

This explains the occurrence of the highest mass concentration on Tuesday.

Figure 9 shows the hourly mean number and mass concentrations of the PM recorded from Sunday to Friday in the living room. The highest maximum hourly mean mass concentration of TSP occurred on Tuesday ($685.31 \ \mu g/m^3$) while the living room was being cleaned from 11:00 to 12:30, which likely led to a large amount of dust being released and suspended. This activity is performed in the common areas of the station once a week by all the occupants.

Note the peaks of the number and mass concentration during breakfast (usually approximately 08:00) and lunch (usually approximately 12:00), when a large number of people occupy the living room. The amount of
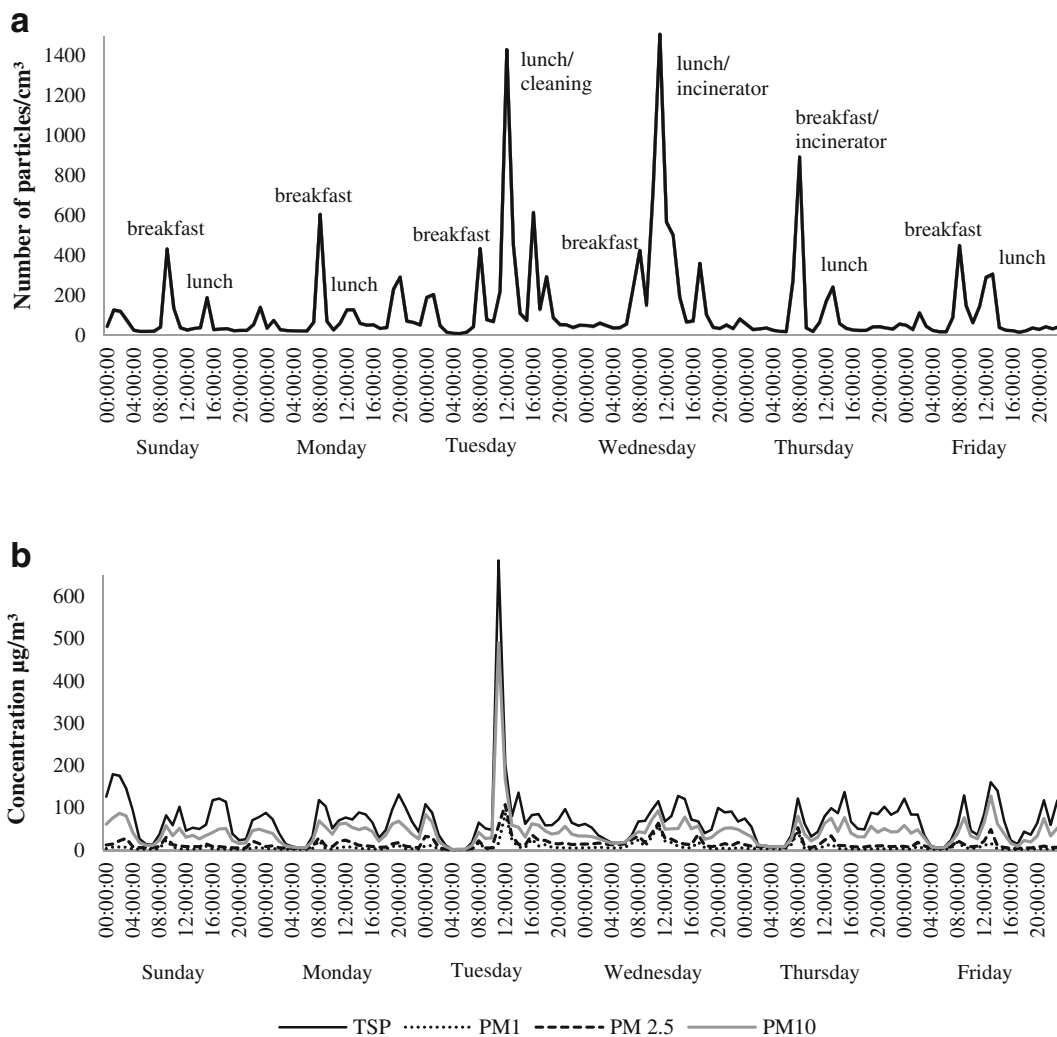
Fig. 9 Hourly mean **a** number and **b** mass concentration of particles in the living room, from Sunday to Friday

time spent cooking, type of oil used for frying, the kitchen layout and the local exhaust ventilation system influence particles concentration, particularly, the fine fractions of PM (Géhin et al. 2008). Evening dining only brings together a small number of people, and food is not usually freshly prepared. Therefore, a significant peak of concentration is not seen during this activity (approximately 20:00 on most days), except on Monday, when fried food was prepared for dinner. The minor peaks of concentration were observed on most days approximately 00:00 and were related to people gathering in the room.

Although the measurements carried out on Tuesday showed the maximum mass concentration of TSP and PM_{10}, as well as $PM_{2.5}$ and PM_1, these values are transitory, as the cleaning activity only lasted for a period of 1.5 h. In contrast, the duration of incineration is much longer and contributed to an increase of particles throughout Wednesday.

According to Seaman et al. (2009) and Tan et al. (2013), combustion sources, such as cooking events and incineration, are one of the main sources of PM_1 and $PM_{2.5}$ in non-smoking indoor environments. It is interesting to note that, despite the fact that cooking activities influence particle concentration in the living room, peaks of mass concentration shown in Fig. 9b are mainly related to PM_{10} and TSP, while PM_1 and $PM_{2.5}$ mass concentrations do not vary significantly. This trend suggests that other human activities, such as cleaning and people movement, tend to be very important for particle emission, since these activities have a tendency to generate particles greater than 1 μm, as already demonstrated by earlier studies, such as Abt et al. (2000) and McDonagh and Byrne (2014). However, on Wednesday and Thursday, there are distinct PM_1 and $PM_{2.5}$ mass concentration peaks, which are mainly related to the incinerator operation influence upon the living room air quality. This behaviour clearly illustrates the importance of the characteristic of particle size distribution in each source upon indoor air quality.

Conclusions

The novelty of this work consists in characterizing the indoor airborne particles and their sources in a research station in Antarctica. Chemical analysis of the fine particles revealed that Fe, Cl, Na, S, Zn, Ca and Si were the main elements found in the living room. Other elements, such as K, Mn and Ni, were also found there, or in other conditioned compartments. In the unconditioned compartments, Na, K, Fe, Zn, Cl, S and Si prevailed, while for the outdoor sites, Cl and Na were the dominant elements. BC was mainly found in the garage and in the workshop. The chemical analyses indicated that the indoor aerosol is mainly generated by the regular indoor activities (cleaning, cooking, hygiene and personal care, circulation, maintenance, etc.); additionally, there were contributions from the use of diesel vehicles and machines and also from the sea spray and crustal coming with the external air admitted in the station.

To identify the human activities related to the indoor particle emission in the station, the size distribution of the particles in the living room was monitored for seven consecutive days, during normal station operation. The influence of individual processes, such as incineration, cooking and people circulation, upon the particle size number concentration was identified.

The I/O ratio for the TSP, PM_{10}, $PM_{2.5}$ and PM_1 measured were significantly larger than those reported for urban buildings (Morawska and Salthammer 2003; Morawska et al. 2013).

In general, the I/O ratio number distribution for all compartments shows a peak between 2.5 and 10 μm, which is often related to human activity, such as cleaning, personnel circulation or clothing surfaces. The maximum I/O ratio at this range varied from 3 to 60. For unconditioned compartments (service areas), the I/O ratio distribution is highly dependent on the type of activity (incineration, welding, painting, carpentry and the transit of vehicles and people). The unconditioned compartments present distributions with the significant presence of even larger particles in relation to the conditioned compartments. In addition, the compartments affected by combustion processes tend to present a significant number of submicron particles.

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